

IMPROVED BOUNDARY SCAN OF INTEGRATED CIRCUITS

Field of the Invention

5 This invention relates to the field of integrated circuits. More specifically the invention relates to the boundary scan test of integrated circuits.

Background of the Invention

10 As integrated circuits become more complex, it becomes increasingly necessary to implement thorough testing for verifying functionality and conformance to specifications. At the same time the shrinking size of integrated circuits as well as the accelerating speed requirements of devices have propelled the development of smaller and faster testing methods. Various standards bodies have also been involved in developing test standards in an effort towards promoting standardization of test methods. To this end a "boundary-scan" testing specification was proposed and
15 developed by the Joint Test Action Group (JTAG) which was later standardized as the IEEE standards 1149.1 specification. This boundary-scan test architecture offers the capability to test components efficiently whether embedded in assembled printed circuit board assemblies or in the form of integrated circuit devices.

20 The Boundary Scan Test architecture is capable of testing pin connections without using physical test probes. It is also capable of capturing functional data while a device is in normal operation. The boundary scan process can force signals onto pins, or capture data from pin or core logic signals. Captured test data is serially shifted into special boundary scan cells from where it can be serially shifted out and compared to expected results externally.

25 Boundary scan register cells are placed such that the state of each digital system pin can be controlled or observed using the boundary scan register. These cells may also allow the state of the system logic inputs and outputs to be controlled and observed respectively.

30 While the implementation of conventional IEEE 1149.1 compliant interfaces within components, such as integrated circuit chips, facilitates higher quality, low cost testing without the need for disclosure of the internal circuitry of the components

under test, these benefits come at the expense of performance due to the signal path delay associated with boundary scan cells. Because of the performance penalty associated with conventional IEEE 1149.1-compliant boundary scan cells manufacturers have resisted compliance with the IEEE 1149.1 standard.

5 U.S. Patent No. **6,266,793**, proposes a method for boundary scanning with increased testability by adding one extra signal to the standard methods, so that input buffers and output buffers are also testable in a two bit bi-directional boundary scan cell. However this method can not be implemented with the standard "INTEST" instruction defined by IEEE standard 1149.1.

10 SUMMARY OF THE INVENTION

The object of this invention is to provide a method and device for boundary scan testing of integrated chips, in a manner that fully conforms to the IEEE standard 1149.1 in an efficient manner and in a small size.

15 Another object of this invention is to increase the operational speed of the boundary scan test process.

To achieve these and other objectives this invention provides an improved 2-bit boundary scan test circuit capable of applying boundary scan test vectors to the input of the core logic of a circuit, using a multiplexer for selectively coupling the output of a boundary scan register to the input of a boundary scan register or to the input of the core logic, and a selection circuit for controlling the multiplexer to enable the coupling when test vectors are required to be applied to the core. The invention also provides a method for improving a 2-bit boundary scan test circuit to provide the capability of applying boundary scan test vectors to the input of the core logic of the circuit, by providing a multiplexing arrangement to enable the selective coupling of the output of a boundary scan test register to the input of the core logic, and an arrangement for selectively enabling the multiplexing arrangement for coupling the output of the boundary scan test register when the test vectors are required to be applied to the core logic.

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BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the accompanying drawings.

5 **Figure 1** shows the schematic logic diagram of a prior art JTAG boundary-scan cell containing three bit bi-directional boundary scan cell.

Figure 2 is a schematic logic diagram of another prior art JTAG boundary-scan cell containing two bit bi-directional boundary scan cell.

Figure 3 shows schematic logic diagram of another prior art JTAG boundary-scan cell containing two bit boundary scan cell and enhanced testing capability.

10 **Figure 4** shows schematic logic diagram of one embodiment of the boundary scan cell of the present invention having two bit boundary scan cell and added circuitry extends the use of boundary scan cell shown in FIG. 2 with every standard instruction.

15 **Figure 5** is a logic schematic diagram of another embodiment of the boundary scan cell of the present invention with slight modification of FIG. 4 to enhance testability more than as in FIG. 3 using minimal signal and hard-ware.

DETAILED DESCRIPTION

20 The invention will now described according to the accompanying drawings. The present invention is illustrated by way of example, and is not limited to the specific implementations of the accompanying figures or description.

25 **Figure 1** shows a circuit for realizing a boundary scan cell according to the IEEE std. JTAG specification. In the full IEEE JTAG implementation, the boundary scan cell includes an input portion, an output portion, and a scan cell portion for providing tri-state control. Multiplexer **111** selects data to be coupled to a JTAG output capture register **112** from either the core logic **P_OUT** circuitry of the IC or from a previous stage. The selection is controlled by signal **shift/capture** from control logic JTAG circuit coupled to multiplexer **111**. The capture register **112** can be loaded externally (from one of the five JTAG pins), or can capture data from one of the previous test clock cycles.

The **shift/capture** signal enables the data capture directly from the core logic **P_OUT**, **P_TS**, from the input buffer **125** or from the previous scanning stage. This last operation involves shifting all of the register stages of the boundary scan cell in a daisy chain. The JTAG data input pin is connected to the input of the first element
5 **SCAN IN** in the daisy chain, and the output of the last element in the chain is connected to the JTAG output pin **SCAN OUT**. The registers get loaded during this process with data and can then be shifted until the desired stage has been reached.

An update register **113** is used on completion of shifting operation for proper alignment and presentation of the data at the output buffer **115**. The output of register
10 **113** is connected to one of the inputs of multiplexer **114**, the second input of the multiplexer being connected directly to the core logic **P_OUT** with the output connected to buffer **115**. Buffer **115** is controlled by signal line **116**, and the output of the buffer is connected to pad **120** and routed to multiplexers **121**, **124** through buffer **125**. Buffer **125** is utilized to drive the voltage signal either the core logic **P_IN** of the
15 IC via multiplexer **121**, or to an input capture register **123**. Multiplexer **124** selects either the input buffer **125**, or the previous scan stage data captured in previous boundary scan cell. The selection is controlled by **shift/capture** signal. The output of multiplexer **124** connects to the input of capture register **123**. The capture register **123** updates register **122**, which can be routed back to the core logic via multiplexer **121**.
20 Multiplexers **121**, **114**, **134** are controlled by the **mode** signal. The signal **116** is the control signal for the buffer **115**. The output of multiplexer **134** is the signal **116**, which is either the captured data from control update register **133** or the control signal from the core logic **P_TS**. The input of control update register comes from control capture register **132**. The control capture register selects between the tri-state signal
25 from core, or data from previous scan stage through multiplexer **131**. Multiplexer **131** is controlled by shift/capture signal.

This method for realizing a boundary scan design requires a substantial amount of circuitry which in turn increases the cost of operation, area of the chip, power consumption and introduces additional delays that reduce the speed of the
30 device.

Figure 2 shows another prior art implementation of boundary scan circuitry that reduces the number of the registers used, in exchange for forgoing the **INTEST**

capacity of the device. In this scan architecture only two capture registers **242**, **252** are connected to the **SCAN_IN** input in a daisy connection through multiplexers **241**, **251**. The output **SCAN_OUT** of the capture register **252** serves as the line output for the serial scan of the daisy chained connection. The inputs of update registers **243** and **253** are connected to the outputs of capture registers **242** and **252** respectively. The outputs of the update registers **243**, **253** are connected to the input of multiplexers **244** and **254**. The output of multiplexer **244** is connected to the input of buffer **245** and the output **255** of multiplexer **254** controls buffer **245**. The output of buffer **245** connects to pad **260**, **P_IN**, and also serves as one of the inputs to multiplexer **240**, through buffer **246**. The core logic output **P_OUT** serves as the second input to multiplexers **240** and **244**, while control signal **P_TS** serves as the second input to multiplexers **251** and **254**. The second input to multiplexer **241** is the output of multiplexer **240**. The select input of the multiplexer **240** is also the control signal of buffer **245**. Multiplexers **241** and **251** share the same select control which also serves as the **shift/capture** pin. The select pins for the multiplexer **244**, **254** are the **MODE** select lines. The **MODE** select line selects the mode of the operation of the device i.e. it determines whether the data is to be sent directly from the core to IO pad or visa-versa.

The operation of the circuit is similar to the operation of the circuit of **figure 1**. However this architecture is not capable of performing the **INTEST** function of the IEEE standard. Output buffer **245** is enabled by signal **255** that selects output data from core of IC for capture register **242** through multiplexer **240**. Further the captured data can be connected to pad **260** through output buffer **245**. When the output buffer is disabled by signal **255**, the data coming from input buffer **246** can be captured in capture register **242**. There is no mechanism for updating of the captured data to the core of IC which is needed for the **INTEST** instruction of IEEE JTAG standard 1149.1.

Figure 3 shows another prior art implementation of the boundary scan architecture offering improved testability and usability. This design enables testing of every path within the boundary scan cell. However the design results in an increased number of nodes. Gates **355** and **348** are introduced for providing extra control pins. Four signals **MODE_1**, **MODE_2**, **EXTEST***, and **CHIP_TEST*** are derived from JTAG decode circuitry. Control signal **EXTEST*** is set 0 when **EXTEST** instruction is to be selected and prevents off-chip test data from reaching the on-chip system

logic through AND gate **348**. Control signal **CHIP_TEST*** is set to 0 when the INTEST or RUNBIST instruction is selected, and set to 1 when SAMPLE/PRELOAD or EXTEST instruction is selected and the output buffer is enabled / disabled accordingly by AND gate **355**. The **MODE_1** and **MODE_2** signals are controlled through JTAG decoder logic depending upon the instruction selected. Multiplexer **340** selects the output from multiplexer **347**, or the output from multiplexer **344**. Multiplexer **340** is controlled by the output signal from multiplexer **354**. The capture of data through multiplexer **340** is controlled by **MODE_1** and **MODE_2**. This architecture requires several extra control signals, which results in extra hardware in JTAG decoder circuitry and occupies more routing area of the IC.

Figure 4 shows the schematic diagram of boundary scan architecture in accordance with the present invention. Two capture registers **442** and **452** are connected in daisy chain through multiplexers **441** and **451**. The **SCAN IN** is connected to one of the inputs of multiplexer **441** and the **SCAN OUT** as the output of the capture register **452**. The output of registers **442** and **452** are applied to the update registers **443** and **453** respectively the outputs of which are connected to the inputs of multiplexers **444** and **454**. The output of multiplexer **444** is applied to the input of buffer **445** and the output **455** of multiplexer **454** controls buffer **445**. The output of buffer **445** connects to pad **460**, and also serves as one of the inputs to multiplexer **440**, through buffer **446** and multiplexer **448**. The output can also be connected as an input to the core logic **P_IN** through buffer **446** and multiplexer **448**. The core logic output **P_OUT** serves as the second input to multiplexers **440** and **444**, while control signal **P_TS** serves as the second input to multiplexers **451** and **454**. The second input to multiplexer **441** is the output of multiplexer **440**. The select input of multiplexer **440** is the control signal of buffer **445**. Multiplexers **441** and **451** share the same select control, which serves as the **shift/capture** pin for the circuit. The select pin for multiplexers **444**, **448** and **454** is the **MODE** select line which is also one of the select lines for multiplexer **448** while the second select line of multiplexer **448** is control signal **455** which serves as the select MSB for the multiplexer. This architecture is capable of implementing all the IEEE 1149.1 Std instructions and tests while using only a two bit boundary scan cell, reducing one cell in terms of hardware, thereby providing a reduced scan chain and increasing the testing speed. This arrangement also provides for the simultaneous testing of EXTEST and INTEST

instructions, resulting in increased testing speed. The output of multiplexer 448 is selected by signal 455 (msb) from multiplexer 454 and JTAG mode signal (lsb). The multiplexer 448 selects captured data, or data from input buffer for the core logic of the IC. At the same time multiplexer 440 always selects data coming from input
5 buffer when the boundary scan cell works as input, enabling EXTEST and INTEST instructions to operate independently or simultaneously. This arrangement uses less area, and less hardware resulting in smaller size. At the same time the novelty of performing EXTEST and INTEST simultaneously reduces the testing time.

Figure 5 shows another embodiment of the present invention. In this
10 embodiment two input multiplexer 440 of the figure 4 is replaced by a four input multiplexer 549 such that P_IN, P_OUT and output of the buffer 546 are the inputs of the multiplexer. The control signal of buffer 545 serves as one of the select lines while the second select line 557 is the logical output of the logic 556. The signal
15 MODE_1 is the first input to the 2-input AND gate 556 and the second input is MODE_2. The main advantage of this embodiment is that it can test output buffers of bi-directional pads, which is not possible with any of the previous two bit boundary scan cell designs.

It will be apparent to those with ordinary skill in the art that the foregoing is merely illustrative and is not intended to be exhaustive or limiting, having been
20 presented by way of example only and that various modifications can be made within the scope of the above invention.

Accordingly, this invention is not to be considered limited to the specific examples chosen for purposes of disclosure, but rather to cover all changes and modifications, which do not constitute departures from the permissible scope of the
25 present invention. The invention is therefore not limited by the description contained herein or by the drawings, but only by the claims.